

Electron-Cloud Build-Up Simulations for the FNAL Main Injector: 400-ns Bunch Spacing*

M. A. Furman,[†] Center for Beam Physics, LBNL, Berkeley, CA 94720-8211, USA

Abstract

We present simulation results of the electron-cloud build-up in a field-free region of the FNAL Main Injector (MI) for a fill pattern in which the full beam consists of only 4 bunches spaced by 400 ns, each having a bunch population $N_b = 30 \times 10^{10}$. We conclude that the one-turn averaged signal expected from the RFA electron detector in this case is ~ 5 orders of magnitude smaller than that observed for more typical fill patterns (3–5 bunch trains of 81 bunches each, spaced by ~ 19 ns, each having $N_b \sim 10 \times 10^{10}$ [1]).

INTRODUCTION

In Ref. 1 we presented electron-cloud build-up simulations for the MI for several fill patterns consisting of 3–5 trains, each of which had 81 consecutive bunches ($f_{\text{RF}} = 53$ MHz) with a bunch intensity in the range $N_b \sim (7 - 10) \times 10^{10}$. These fill patterns were used last year to obtain a set of electron-cloud measurements [2, 3] with a RFA-type detector installed in a field-free section of the MI. By comparing the measured RFA signal against our simulations, and using some reasonable assumptions, we were able to constraint the value of the peak secondary emission yield (SEY) to the range $\delta_{\text{max}} \sim 1.25 - 1.35$.

In this note we simulate the electron-cloud effect for a very different fill pattern, namely a beam consisting of only 4 bunches, each of intensity $N_b = 30 \times 10^{10}$, spaced by 21 RF buckets (398 ns). Such a fill pattern is presently feasible [4] and the electron cloud should be, in principle, observable via the RFA signal. The motivation for the present simulation effort is to test the simulation code in a rather different parameter regime from the previous study, and thus (hopefully) strengthen its predictive power. In addition, we wish to examine the electron-cloud effect for ever higher bunch intensities in the MI, in anticipation of its intensity upgrade.

RESULTS

As in the previous study [1], we only look at the field-free region where the RFA is installed, and we vary δ_{max} in the range where the previous results indicated agreement with measurements. We only simulate the beam for one full turn at injection energy, $E_b = 8.9$ GeV. The main parameters are shown in Tab. 1. A discussion of some of the parameter choices is presented in Ref. 1.

Table 1: Assumed MI parameters for EC simulations.

Ring and beam	
Ring circumference	$C = 3319.419$ m
Revolution period	$T_0 = 11.13$ μ s
RF frequency	$f_{\text{RF}} = 52.809$ MHz
Harmonic number	$h = 588$
Beam energy	$E_b = 8.9$ GeV
Bunch profile	3D gaussian
Tr. RMS bunch sizes	$(\sigma_x, \sigma_y) = (2.3, 2.8)$ mm
95% bunch duration	$\tau_{95\%} = 14$ ns
RMS bunch length	$\sigma_z = 1.06$ m
Pipe cross sect. at RFA	round
Pipe radius at RFA	$a = 7.3$ cm
Primary e^- sources	
Resid. gas pressure	$P = 20$ nTorr
Temperature	$T = 305$ K
Ioniz. cross-section	$\sigma_i = 2$ Mbarns
Ioniz. e^- creation rate	1.266×10^{-7} (e/p)/m
Secondary e^- parameters	
Range of peak SEY	$\delta_{\text{max}} = 1.2 - 1.4$
Energy at δ_{max}	$E_{\text{max}} = 292.6$ eV
SEY at 0 energy	$\delta(0) = 0.2438 \times \delta_{\text{max}}$
Simulation parameters	
Full bunch length	$L_b = 5\sigma_z$
Primary macroelectrons/bunch	100
Max. no. of macroelectrons	20000
No. kicks in L_b	$N_k = 357$
Integration time step	5×10^{-11} s
Space-charge grid	64×64

Results for the simulated incident electron flux J_e on the chamber walls during the electron-cloud buildup are shown in Fig. 1, and the corresponding electron number density n_e is shown in Fig. 2.

The values of J_e shown in Figs. 1 and 3 are obtained by averaging the incident electron flux over the entire surface of the chamber. In practice, the RFA measures only the flux within a circular area of 1" diameter centered at the top of the chamber. However, we have checked that the simulated whole-chamber flux is within a few percent of the flux in the RFA region, as it should be expected given the approximately circular geometry of the problem. The whole-surface average, of course, has the advantage of much reduced statistical noise relative to the RFA average.

The one-turn averages of the above quantities are plotted vs. δ_{max} in Fig. 3. Given that the previous results [1] indi-

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[†] mafurman@lbl.gov

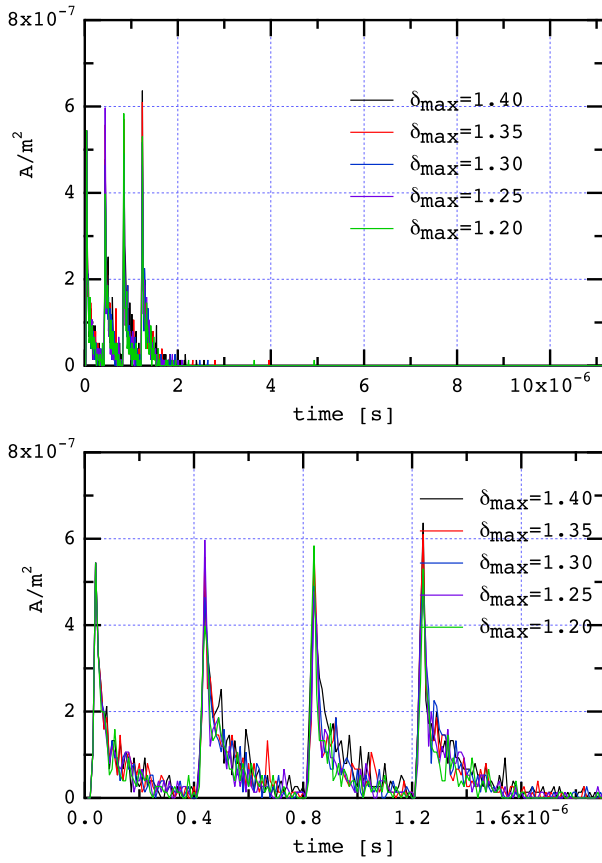


Figure 1: Build-up of the simulated incident electron flux J_e on the vacuum chamber walls during one turn ($T_0 = 11.1 \mu\text{s}$, top), and during the first $1.9 \mu\text{s}$ (bottom).

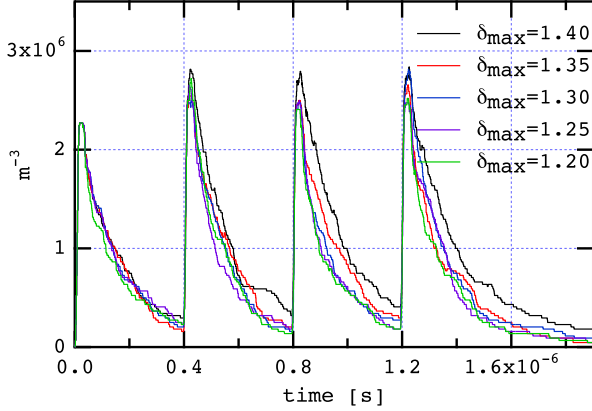


Figure 2: Build-up of the simulated electron number density n_e .

ated $\delta_{\text{max}} \sim 1.3$, we conclude that the expected electron-wall incident flux in the present case is $J_e \sim 1 \times 10^{-8} \text{ A/m}^2$ and the number density $n_e \sim 1 \times 10^5 \text{ m}^{-3}$. This value of J_e should be compared with the previous analysis and measurements, $J_e \sim (\text{a few}) \times 10^{-3} \text{ A/m}^2$ at the peak of the RFA signal, which typically occurs at $E_b \simeq 60 \text{ GeV}$. We conjecture that the signal in the present case, be-

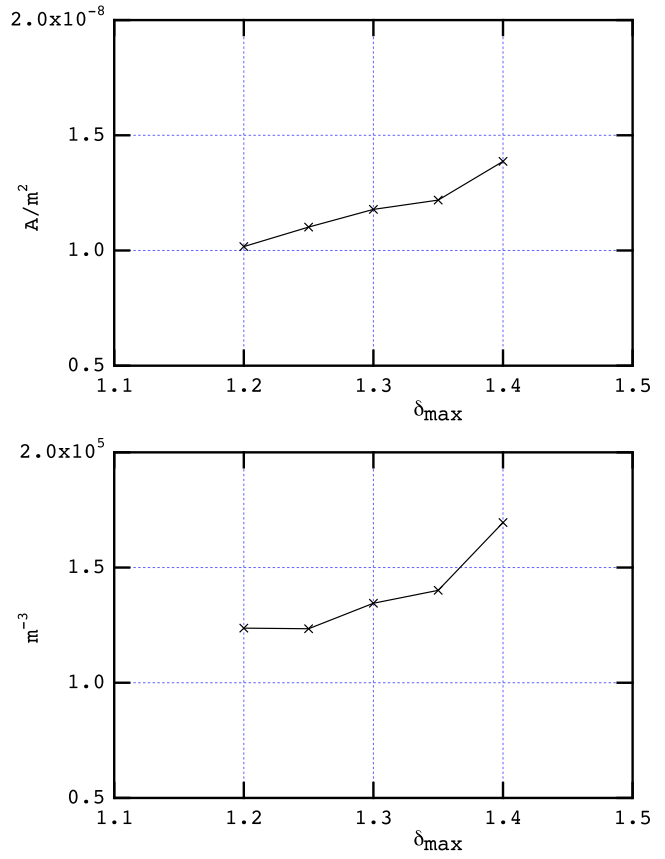


Figure 3: One-turn averages of J_e and n_e plotted vs. the assumed value of the peak SEY, δ_{max} .

ing more than 5 orders of magnitude smaller than in the previous case, is practically unobservable.

The smallness of the effect in this case is primarily a consequence of the fact that the beam consists of only 4 bunches, and that the RFA signal is averaged over one full turn. If, for example, the RFA signal were to be averaged over the first $2 \mu\text{s}$, rather than over $T_0 = 11.1 \mu\text{s}$, the average would be ~ 5 times larger (see Fig. 1), which would still be much smaller than in the previous analysis.

A second reason for the smallness of the electron-cloud effect in this case is the rather large bunch length. The consequence of this is that the energy imparted by the bunch to the electrons is rather small owing to a phase-averaging of the electrons being temporarily trapped inside the bunch. As a result, the average electron-wall impact energy ($\sim 30 \text{ eV}$) is much smaller than the energy at the peak of the SEY curve ($E_{\text{max}} = 293 \text{ eV}$), hence the effective SEY is small hence n_e is small. In a fictitious spot check, we changed the bunch length to 1/10 of the value in Tab. 1, with all other quantities fixed. In this case the electron-wall impact energy turned out to be $\sim 120 \text{ eV}$, leading to a higher effective SEY and hence to a larger n_e and J_e , though only by a factor of ~ 2 .

Our simulations are subject to several caveats, discussed in Ref. 1.

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